Water Temperature Effects on the Discharge Rate of Collapsible Emitting Hose[1]

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Abstract

Lab studies were conducted to measure the effects of water operating temperature on the discharge rate of emitters from thin-walled drip tape (collapsible emitting hose) products. Two different product types (Robert's Ro-Drip, RD; and T-Tape, TT) each with two wall thicknesses were evaluated. The RD product included wall thicknesses of 8 mil (RD08) and 15 mil (RD15) while the TT product included wall thicknesses of 10 mil (TT10) and 15 mil (TT15). Increases in water operating temperature from 69 to 137 ºF doubled the emitter discharge (approximately 0.3 gph) from the RD08 product at both 10 and 12 psi. Emitter discharge rate changes in the RD15 product were not as great (0.03 gph; 10-12% increase) for similar water temperature changes. Effects of water temperature on the discharge rate from the TT products were quite different than the RD products. Emitter discharge rate increased slightly with water temperature at the 8 psi level, but decreased at the 12 psi level. However, decreased flows were less than 0.03 gph or 10% of the original flow rate.

Introduction

The designer of microirrigation systems needs to know how specific products will perform under conditions experienced in the field. Because substantial operating pressure variations can occur in a field system due to elevation changes and friction associated with system hydraulics, most design concerns focus on the operating pressure / emitter discharge relationships of the emitters. The goal is to design a system that will have a hydraulic balance such that a subunit within the system has a known and uniform emitter discharge.

Parchomchuk (1976) measured lateral line temperature increases from 78 to 107 ºF on a bright sunny day for surface positioned polyethylene pipe laterals. Buried laterals (6-in. deep) had a peak measured temperature of 89 ºF. Similar results were reported by Nakayama and Bucks (1985) for 14.5 mm black polyethylene lines in Phoenix, Arizona. Peak water temperatures for surface positioned laterals were measured at 108 ºF in May while empty lines had a peak temperature of 118 ºF. Furthermore, higher temperatures can exist under black polyethylene mulch. Bell and Laemmlen (1991) reported that under clear polyethylene mulch, diurnal temperatures ranged from 75 to 150 ºF at a depth of 2 cm while at a soil depth of 15 cm temperatures ranged from 73 to 127 ºF. Abu-Gharbieh (1997) reported soil temperatures of 122 ºF at 10-15 cm deep and 100 ºF at a depth of 30 cm. Even under these conditions, buried drip irrigation laterals can act as a heat exchanger and absorb heat from the soil thereby increasing the temperature of the water and emitter chambers.

The objectives of this work were to evaluate the discharge rate performance of thin-walled drip tape (collapsible emitting hose) emitters under elevated water temperatures.

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Methods and Materials

Performance tests were conducted on thin-walled drip tape (collapsible emitting hose). Four different products were tested (Tab.1). All products came from the manufacturer on standard rolls. Each drip tape had a reported inside diameter of 0.625 inches. Performance tests focused on the response of drip emitter discharge to water temperature. However, other tests included an elongation test and a standard operating pressure / emitter discharge response test. These latter two tests were used to help characterize the base conditions of the tubing. All tests were conducted in the hydraulic lab in the Department of Biological and Agricultural Engineering at Kansas State University and followed procedures as outlined in ASAE Standard S553 (2001).

Table 1. Drip tape products tested.

Product Code	Manufacturer§	Wall Thickness (mil)	Emitter Spacing (in.)	Rated Emitter Discharge£ (gph)
RD08	Roberts Irrigation, Inc	8	12	0.24
RD15	Roberts Irrigation, Inc.	15	8	0.27
TT10	T-Systems International	10	16	0.27
TT15	T-Systems International	15	8	0.27

§ Mention of specific products or manufacturers does not imply endorsement by the authors or by Kansas State University.
£ Discharge at nominal pressure of 8 psi.

Tubing Elongation Tests.

These tests followed procedures in section 8.7 of ASAE Standard S553 (ASAE 2003). Three 60-inch samples of drip tape were cut from the stock roll. A mid-sample section of 40 inches was marked. The upper end of a sample was secured around a pipe for support and a bucket was attached to the lower end to hold water that was added to increase applied weight. The upper end pipe support was hung from anchors attached to a vertical support column in the hydraulics lab. Water was added to the bucket in 4.5 lb increments. After each addition of weight, the tubing was allowed to stabilize for 2 minutes. Elongation was then measured between the originally marked points by using a tape measure. Weight was added until a sample ruptured or elongated more than 25% of the original length. Each test was repeated for 3 samples of each tubing type

Standard Operating Pressure / Emitter Discharge Tests

These tests followed procedures in section 8.3 of ASAE Standard S553 (ASAE 2001) and included five drip tape lateral lines that each had five emitters (Fig. 1). Each lateral was attached to an inlet and distal manifold system. All drip tapes were suspended on a support rack made of 1-inch (nominal) PVC pipe. Emitters from each drip lateral were aligned so that a collection cup rack could be used to simultaneously collect emitter discharge. Small strings (kite string) attached to the drip tape at each emitter extended approximately 6 inches below the drip tape, were saturated during the conditioning periods, and wicked water into the collection cups. Supply water was provided by a 50-gallon reservoir (Fig.1, item 1) that had a small pump used to pressurize the water. Water temperature during these tests was maintained at 73.4 F (±3.6 F). Adjustable pressure regulating valves (Fig.1, item 3) were used to adjust operating pressure. Water operating pressures were incrementally increased between discharge tests from a minimum pressure of 4 psi up to 16 psi in 4 psi increments. Water pressure was measured using a series (0-15, 0-30, and 0-60 psi) of precision Bourdon Tube pressure gauges (Fig. 1, item 2) that were on an adjustable rack so that the gauge level could be consistent with the drip tubing level. Water temperature was measured during each test sequence using both a bimetallic temperature sensor and an electronic thermistor connected to a data logger. Both temperature sensors were inserted into the applied water stream using modified PVC pipe fittings (Fig. 1, item 4). A small nozzle was also attached to the discharge manifold to discharge approximately 0.5 gpm of water. This nozzle discharge was used to maintain flow through the suspended drip tapes and minimize slow internal flow velocities and entrapped air.

During the first test sequence, all drip tapes were conditioned for 15 min at the minimum pressure setting (4 psi). Water discharge amounts from all emitters were collected into small plastic cups over a six-minute collection period. On queue, the collection cup racks were slid under the dripping strings. Then again on queue, collection cups were slid out from under the dripping strings. Collected water volumes were weighed on an electronic balance and converted to volumetric units. Collected amounts typically weighed between 90 and 120 g and the balance had an accuracy of ±0.1 g. All cups were emptied and shaken dry between tests. The water pressure level was adjusted to the next level and drip tubes were then conditioned for 3 minutes at each successive pressure setting prior to collecting discharge volumes.

Drip Tubing Temperature Response

These tests followed procedures in section 8.4 of ASAE Standard S553 (ASAE 2001). Three drip tape lateral lines with five emitters each were tested at each temperature and pressure setting using the previously discussed lab setup (Fig. 1). This test was conducted on each of four different products (Tab. 1). The first sequence of tests evaluated each product at the nominal operating pressure of 8 psi with five water temperature settings (68, 84, 100, 118, and 126°F). Two subsequent series of tests were conducted using operating pressures of 10 and 12 psi and six water temperatures (68, 84, 100, 118, 126, 138°F). New sections of drip tape were used for each operating pressure setting. Operating pressures were established and measured using previously describe procedures.

The water temperature values were target levels. Actual water temperature levels were measured and recorded during each test. The lab tap water temperature ranged between 66 and 70°F. This temperature level was used as the starting point (T_{min}) in all tests. For the first temperature setting in all tests the 50-gallon reservoir was filled with the lab tap water. Temperature sensors were positioned in the reservoir, in the supply pipe to the test manifold, and on the discharge manifold of the testing system. Water temperature readings were digitally and manually recorded during each test to ensure consistent levels throughout the drip tape laterals. For the elevated water temperature tests, water was heated in a standard electric water heater and approximately 20 gallons was added to the 50-gallon reservoir. Cooler tap water and heated water were then added and stirred to obtain a water temperature value close to the next higher target level. Because each water temperature test sequence lasted for less than 30 minutes, the thermal mass of the water in the supply reservoir was sufficient to maintain the elevated water temperature setting during the test sequence.

During a temperature sequence of tests, drip tapes were initially conditioned at the specified pressure setting (8, 10, or 12 psi) and T_{min} (~68°F) for at least one hour. During the test, pressure was maintained at the treatment level. After each test run, the water temperature was increased to the next level as described above, and tubing was conditioned at that temperature level for fifteen minutes. Water discharge amounts from all emitters were collected into small plastic cups over a six-minute collection period using procedures as previously described.

Results

Tubing Elongation Tests

While all elongation responses (Fig. 2) followed a similar trend, product wall thickness and material composition affected the linear elongation response. A load of 35 lbs resulted in a 25% elongation of the RD08 (8 mil) product while 54 lbs was required for a 25% elongation of the RD-15 (15 mil) product. However, while the TT-10 product (10 mil) is thinner than the RD-15 product (15 mil), a load of 58 lbs was required to reach 25% elongation. This demonstrates the difference associated with product composition. The TT-15 product (15 mil) was the stiffest requiring 72 lbs of load to elongate by 25%.

Standard Operating Pressure / Emitter Discharge Tests

Emitter discharge / pressure relationships for the RD (Fig. 3) and TT (Fig. 4) products fit a standard power function that take the form:

$$q_e = kP^x$$

where q_e is the emitter discharge (gph), P is the operating pressure (psi), x is the emitter discharge coefficient, and k is a constant of proportionality. Values of “k” and “x” are summarized for the four products of this study (Tab. 2). These power function regression relationships all had very high R^2-values (>97%). Nominal emitter discharge rates (Tab. 2) were calculated using the respective values of “k” and “x” for each product (Tab. 1).

Table 2. Summary of “k” and “x” values for the drip tape products used in this study. The nominal emitter discharge rate was calculated for each product using the respective values of “k” and “x” at the nominal pressure of 8 psi.

Product	“k”	“x”	R^2	q_{nom} (gph)
RD-08	0.0683	0.66	1.000	0.27
RD-15	0.1186	0.42	0.999	0.28
TT-10	0.0865	0.58	0.976	0.29
TT-15	0.0881	0.56	0.990	0.28

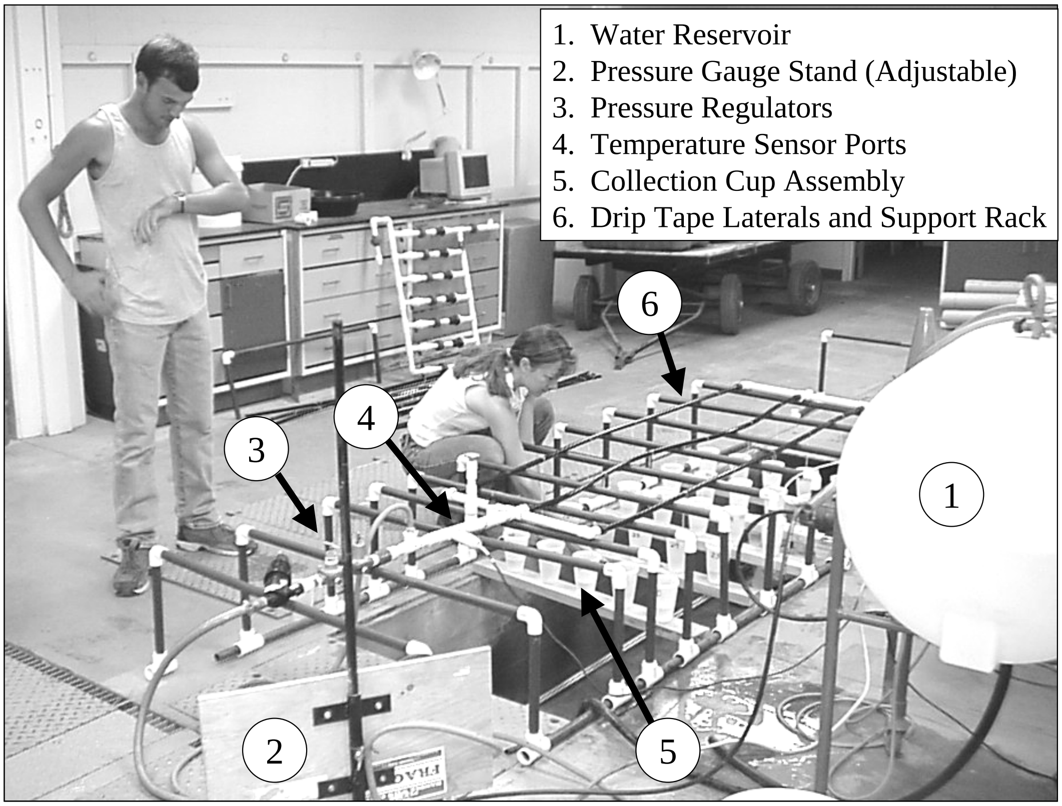

Figure 1. Lab setup to measure drip tape emitter discharge rates.

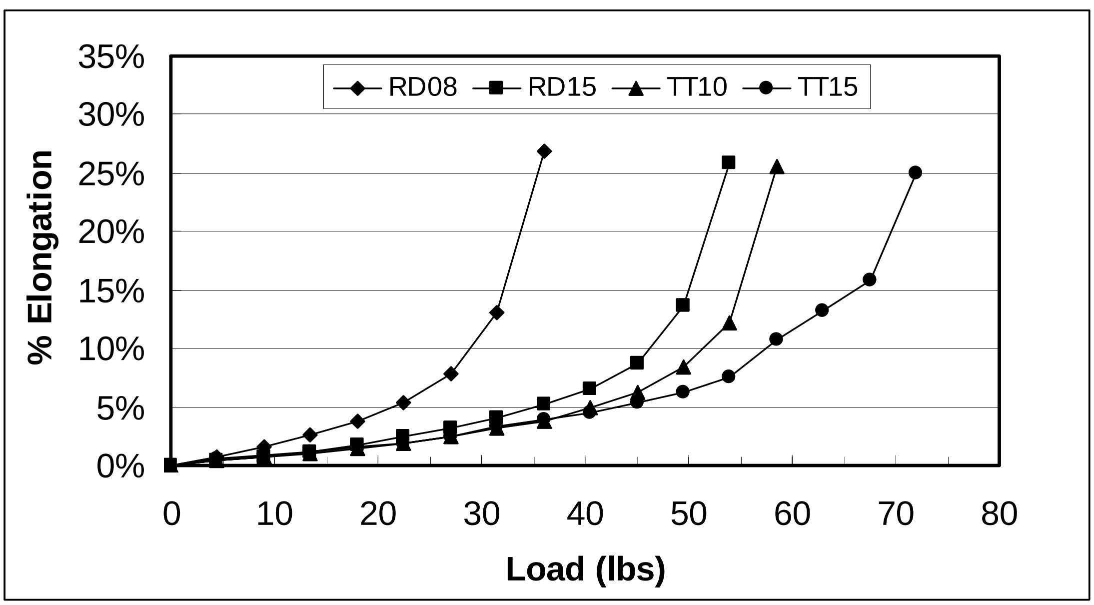

Figure 2. Percentage of tape elongation with respect to applied load (lbs) for the four drip tape products.

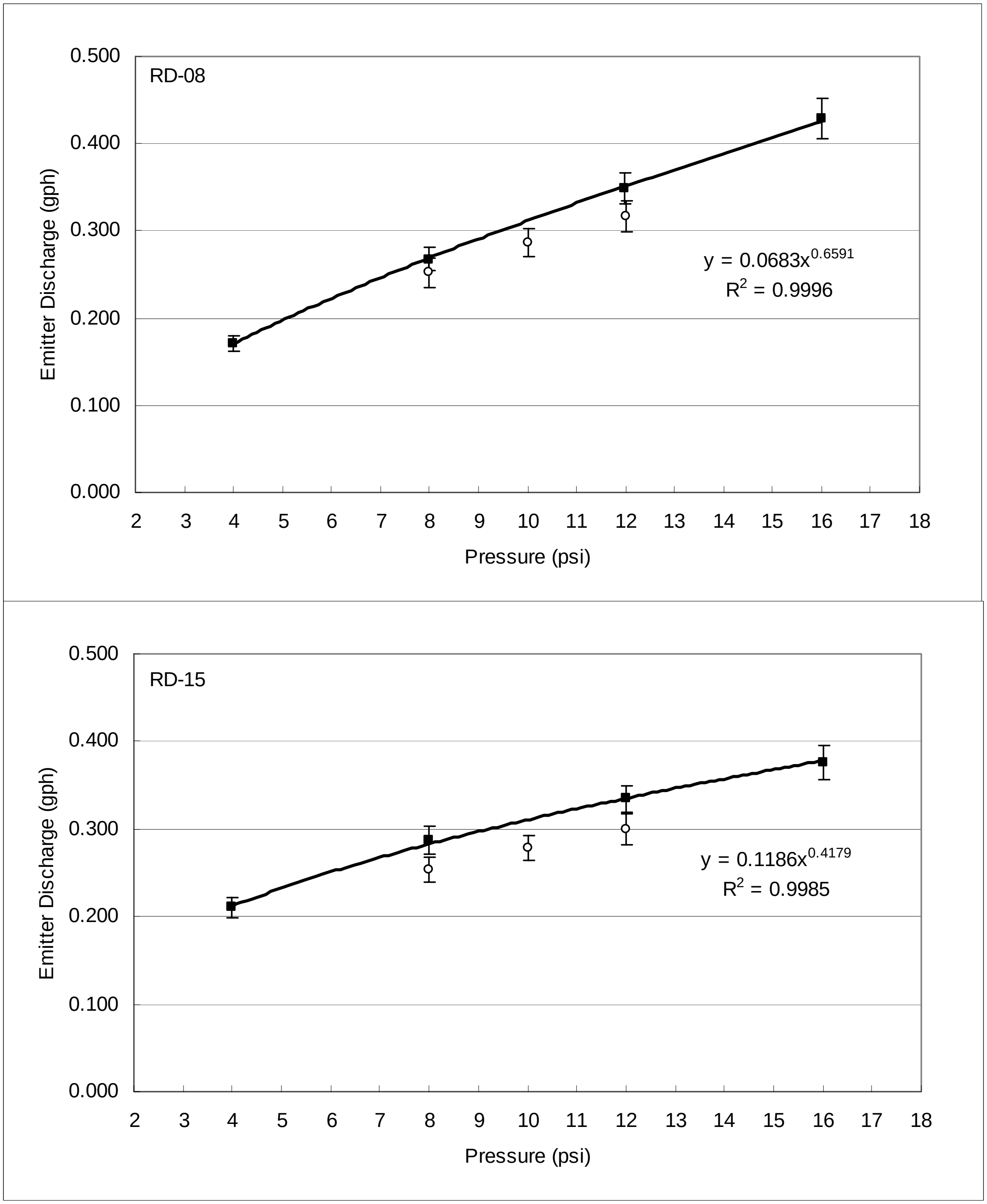

Figure 3. Emitter discharge / pressure relationships for the RD-08 product (upper) and RD-15 product (lower). The original discharge / pressure test data are displayed as solid squares with error bars (± 1 std dev); the power function regression of those data is displayed as a solid line (regression function shown on graph); and baseline emitter discharge data from the water temperature study are displayed as open circles with error bars (± 1 std dev).

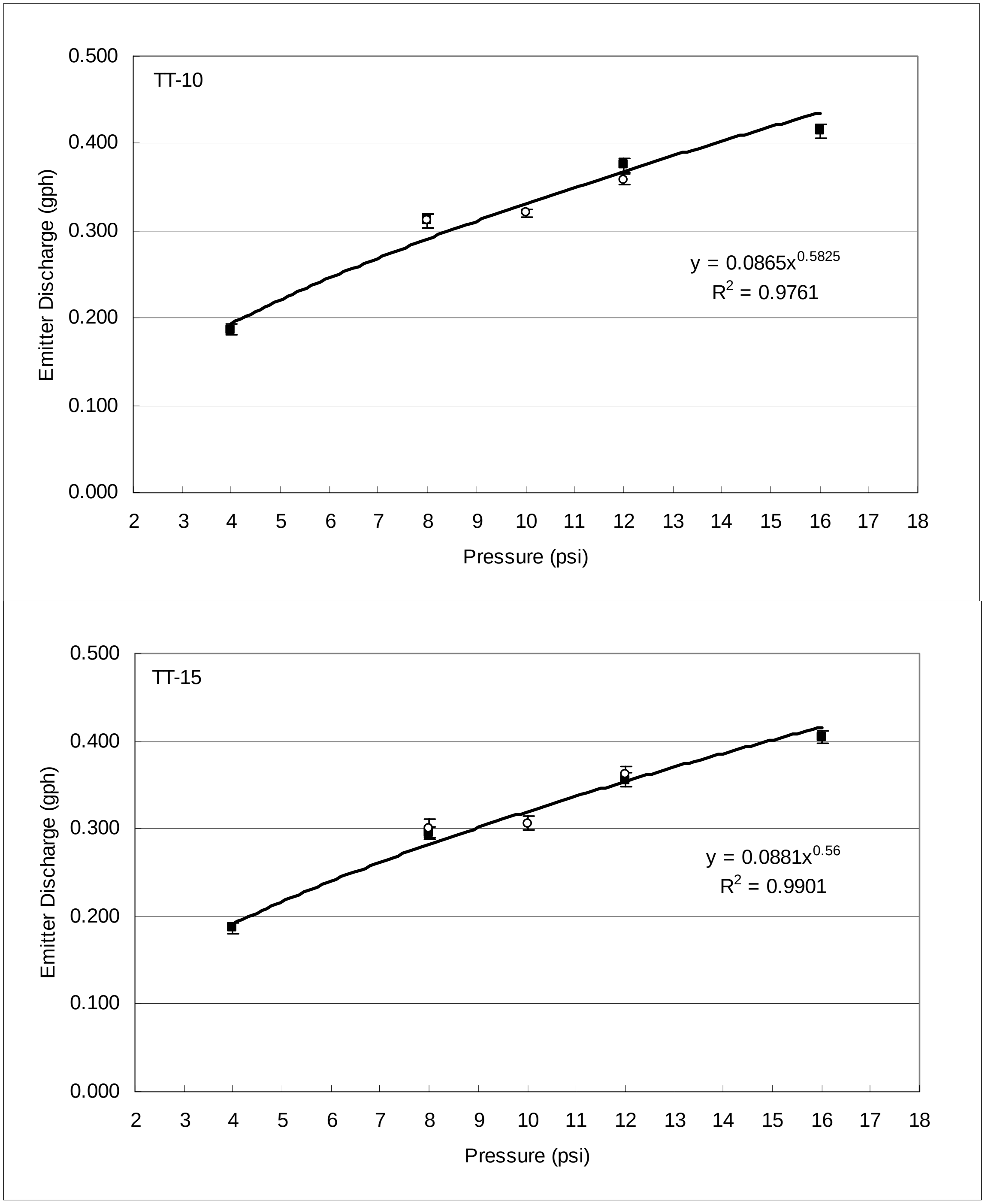

Figure 4. Emitter discharge / pressure relationships for the TT-10 product (upper) and TT-15 product (lower). The original discharge / pressure test data are displayed as solid squares with error bars (± 1 std dev); the power function regression of those data is displayed as a solid line (regression function shown on graph); and baseline emitter discharge data from the water temperature study are displayed as open circles with error bars (± 1 std dev).

The baseline water temperature emitter discharge data for the RD products (Fig. 3) were slightly lower than the previously measured discharge / pressure data. However, the TT product data (Fig. 4) had very good agreement with the discharge / pressure data.

Drip Tubing Temperature Response

Emitter discharge values are presented for each water temperature level at each pressure setting along with the coefficient of variation (cv) of the measured data and the percent change from the baseline water temperature data (Tab. 3, 4, 5, and 6). The RD-08 product had the greatest change in emitter discharge rate with increased water temperature (Tab. 3). At an operating pressure of 8 psi, emitter discharge rate showed little change (1.5%) as water temperature increased from 66 to 83 ºF (26% change). However, these trends were not linear and emitter discharge increased from 0.252 gph to 0.298 gph (18% change) with a water temperature increase from 66 to 125 ºF (89%change). As operating pressure was increased, the effects of increased water temperature on emitter discharge rate were more substantial. At 10 psi, the baseline emitter discharge was 0.287 gph while at a water temperature of 118 ºF the emitter discharge rate was 0.372 gph (+ 29.7%) and at 137 ºF the emitter discharge rate was 0.550 gph, an increase of 91.8%.

Changes in emitter discharge with water temperature for the RD 15 product (Tab. 4) were not as substantial as with the RD08 product. The greatest percentage changes occurred with the 8 psi operating pressure with a 12% increase in discharge rate (0.029 gph) as water temperature increased from 68 to 114 ºF. The stiffer properties of this product (Fig. 2) appear to buffer the effects of increased water temperature

Emitter discharge rate changes in the TT products (Tab. 5 and 6) were quite different from the RD products (Tab. 3 & 4). The TT10 product (Tab.. 4) had a slight increase in emitter discharge (0.015 gph or +4.6%) with a temperature rise from 69 to 125 ºF at an operating pressure of 8 psi. However, emitter discharge rate decreased with increased water temperature at operating pressures of 10 and 12 psi. Decreasing emitter discharge rate results were also measured by Parchumchuk (1976) on vortex type emitters. The greatest decrease occurred at 12 psi with a reduction in emitter discharge of 0.031 gph (-8.8%) as water temperature increased from 67 to 139 ºF. An increase in wall thickness of this product (TT15) reduced the effects of water temperature on emitter discharge (Tab. 4). Emitter discharge changes at pressures of 8 and 10 psi were minimal while at 12 psi emitter discharge rate decreased by 0.022 gph (-6.1%) with a water temperature change from 70 to 138 ºF.

Some variation in emitter response from the RD08 product was measured with coefficient of variation (cv) values ranging from 0.065 to 0.078, 0.047 to 0.055, and 0.053 to 0.069 at the 8-, 10- and 12-psi pressure levels, respectively (Tab. 3). While measured emitter variation with the RD15 product was similar to the RD08 product (Tab. 4), both TT products (TT10 and TT15) had lower cv values (0.014 to 0.036) indicating higher consistency among emitters (Tab. 5 and 6). None of the products showed any trend or substantial change in emitter discharge variation with temperature or pressure.

Table 3. Emitter discharge relationships for the RD08 product at elevated water temperatures for three operating pressures. Data include the operating temperature of the water, the emitter discharge rate (gph), the coefficient of variation of measured flows and the percentage of change from the T_{min} values.

Operating Pressure	**Water Temperature (ºF)**	**Emitter Discharge (gph)**	**Coefficient of Variation**	**%Change (from T_{min})**
8 psi	66	0.252	0.069	0.0%
	83	0.256	0.065	1.5%
	98	0.266	0.071	5.5%
	114	0.281	0.078	11.6%
	125	0.298	0.076	18.3%
10 psi	71	0.287	0.055	0.0%
	85	0.303	0.053	5.6%
	99	0.323	0.053	12.7%
	118	0.372	0.048	29.7%
	123	0.413	0.053	44.0%
	137	0.550	0.047	91.8%
12 psi	69	0.316	0.056	0.0%
	84	0.337	0.054	6.5%
	103	0.390	0.053	23.2%
	117	0.515	0.069	63.0%
	122	0.624	0.065	97.3%
	139	0.531	0.068	68.1%

Table 4. Emitter discharge relationships for the RD15 product at elevated water temperatures for three operating pressures. Data include the operating temperature of the water, the emitter discharge rate (gph), the coefficient of variation of measured flows and the percentage of change from the T_{min} values.

Operating Pressure	**Water Temperature (ºF)**	**Emitter Discharge (gph)**	**Coefficient of Variation**	**%Change**
8 psi	68	0.253	0.056	0.0%
	87	0.274	0.055	8.1%
	103	0.282	0.058	11.3%
	114	0.284	0.062	12.1%
	120	0.284	0.063	12.0%
10 psi	67	0.279	0.052	0.0%
	86	0.289	0.073	3.6%
	101	0.286	0.057	2.7%
	118	0.294	0.056	5.5%
	126	0.296	0.063	6.1%
	139	0.306	0.051	9.8%
12 psi	69	0.300	0.058	0.0%
	84	0.309	0.055	3.0%
	99	0.313	0.055	4.3%
	117	0.321	0.053	6.9%
	127	0.330	0.050	10.2%
	131	0.335	0.048	11.6%

Table 5. Emitter discharge relationships for the TT10 product at elevated water temperatures for three operating pressures. Data include the operating temperature of the water, the emitter discharge rate (gph), the coefficient of variation of measured flows and the percentage of change from the T_{min} values.

Operating Pressure	**Water Temperature (ºF)**	**Emitter Discharge (gph)**	**Coefficient of Variation**	**%Change**
8 psi	69	0.311	0.026	0.0%
	84	0.317	0.025	1.8%
	100	0.322	0.029	3.5%
	117	0.325	0.025	4.2%
	125	0.326	0.023	4.6%
10 psi	67	0.321	0.015	0.0%
	84	0.315	0.017	-1.6%
	101	0.315	0.018	-1.7%
	119	0.312	0.014	-2.6%
	126	0.307	0.015	-4.3%
	138	0.304	0.019	-5.2%
12 psi	67	0.358	0.018	0.0%
	85	0.344	0.017	-4.0%
	101	0.339	0.016	-5.5%
	118	0.333	0.018	-7.0%
	126	0.333	0.016	-7.1%
	139	0.327	0.017	-8.8%

Table 6. Emitter discharge relationships for the TT15 product at elevated water temperatures for three operating pressures. Data include the operating temperature of the water, the emitter discharge rate (gph), the coefficient of variation of measured flows and the percentage of change from the T_{min} values.

Operating Pressure	**Water Temperature (ºF)**	**Emitter Discharge (gph)**	**Coefficient of Variation**	**%Change**
8 psi	67	0.300	0.036	0.0%
	82	0.300	0.029	0.1%
	96	0.301	0.033	0.4%
	112	0.301	0.032	0.3%
	122	0.302	0.028	0.6%
10 psi	69	0.306	0.024	0.0%
	85	0.313	0.019	2.1%
	99	0.313	0.025	2.1%
	116	0.313	0.020	2.3%
	124	0.309	0.018	0.9%
	135	0.305	0.017	-0.5%
12 psi	70	0.363	0.020	0.0%
	85	0.357	0.020	-1.8%
	101	0.353	0.018	-2.7%
	116	0.346	0.017	-4.7%
	126	0.343	0.016	-5.6%
	138	0.341	0.016	-6.1%

Summary and Conclusions

Lab studies were conducted to measure the effects of water operating temperature on the discharge rate of emitters from thin-walled drip tape (collapsible emitting hose) products. Two different product types (Robert's Ro-Drip, RD; and T-Tape, TT) each with two wall thicknesses were evaluated. The RD product included wall thicknesses of 8 mil (RD08) and 15 mil (RD15) while the TT product included wall thicknesses of 10 mil (TT10) and 15 mil (TT15). These two product types were made of different plastic materials and had different material properties. The RD product was more elastic than the TT product. The load required to provide a 25% increase in length was 35, 54, 58, and 72 lbs for the RD08, RD15, TT10, and TT15 products, respectively.

Increases in water operating temperature from 69 to 137 ºF doubled the emitter discharge (approximately 0.3 gph) from the RD08 product at both 10 and 12 psi. Emitter discharge rate changes in the RD15 product were not as great (0.03 gph; 10-12% increase) for similar water temperature changes. Thus, wall thickness appears to have buffered the water temperature effects.

The effects of water temperature on the discharge rate from the TT products were quite different than the RD products. Emitter discharge rate increased slightly with water temperature at the 8 psi level, but decreased at the 12 psi level. However, decreased flows were less than 0.03 gph or 10% of the original flow rate.

Results of these studies clearly indicate the need to know the effects of water temperature on the emitter discharge relationships of thin-walled drip tape products. Substantial discharge differences associated with water (or soil) temperature can affect the "as-built" characteristics of the system design, pump output, system / subunit uniformity, and/or pressure distribution. Temperature measurements and associated corrections may also be necessary during field performance evaluations of these systems.

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